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Title: Heavy Flavor and jet studies for the future Electron Ion Collider

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DNP2020
Fall Meeting of the Division of Nuclear Physics of the American Physical Society
Oct. 29 – Nov. 1, 2020 *Now Virtual Meeting!*
~~Hyatt Regency Hotel, New Orleans, LA~~
APS physics

Heavy Flavor and jet studies for the future Electron-Ion Collider

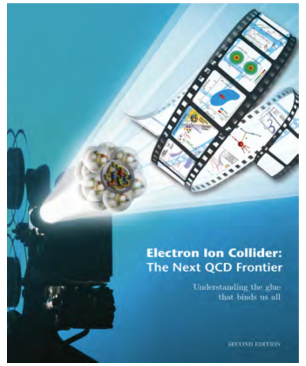
Xuan Li (xuanli@lanl.gov)
on behalf of Los Alamos National Laboratory

Outline

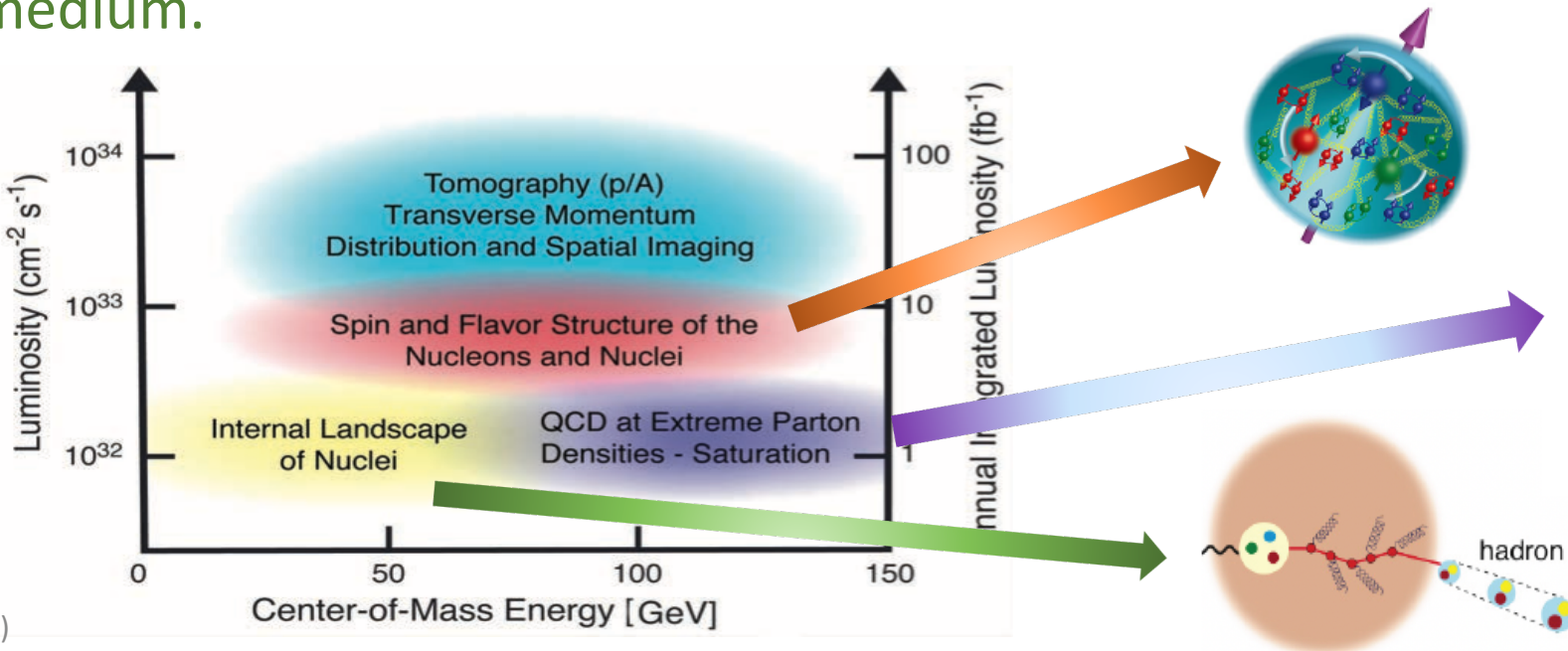
- Motivation.
- Initial detector design and tracking performance.
- Open heavy flavor and jet studies in simulation.
- Summary and outlook.

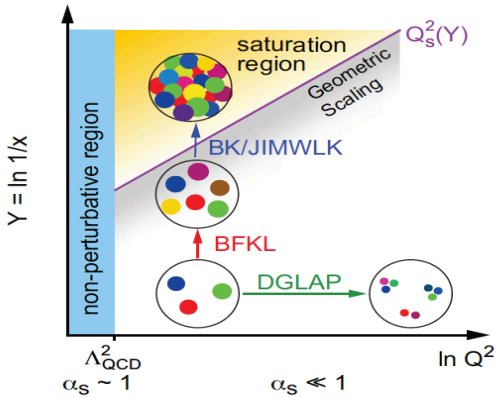
New QCD frontier: the Electron-Ion Collider (EIC)

- EIC can help solve several fundamental physics problems in a wide x_{BJ} and Q^2 kinematic region.
  - How quarks and gluons distributed in momentum and space within the nucleon and a heavy nuclei?
  - Proton spin origin?
  - What happens to the gluon density in nuclei, does it saturate at high energy?
  - A clean environment to study the flavor dependent energy loss in nuclear medium.



A. Accardi et al, **Eur. Phy. J. A**, 52 9 (2016).

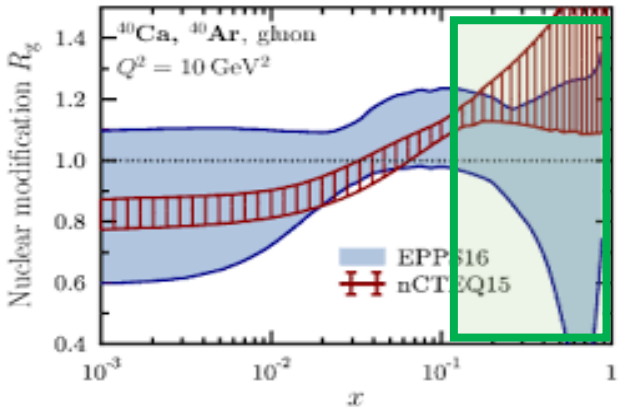




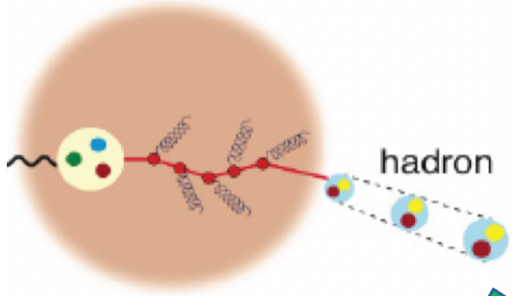
Critical EIC physics probes: heavy flavor and jet production

- Through measuring heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the hadron/nuclei going (forward) direction in e+p/A collisions at the EIC.

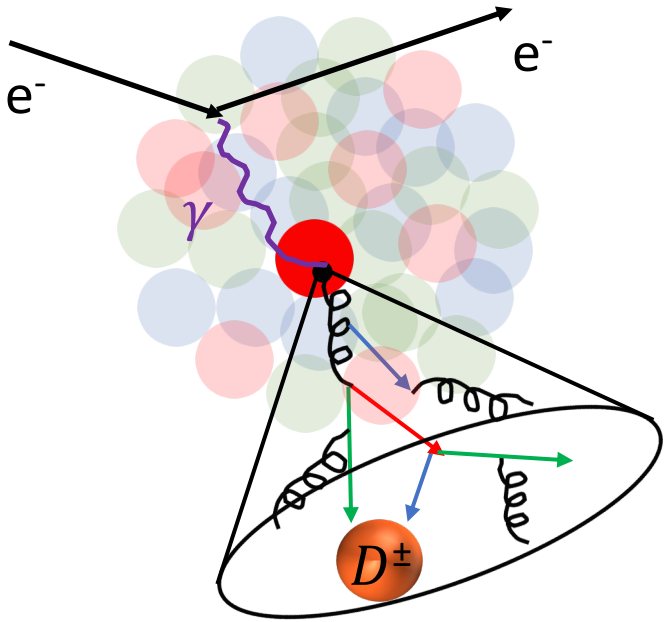
nPDF modification



Parton energy loss



$e^- + \mathrm{Au} \rightarrow e^- + jet(D^{\pm}) + X$

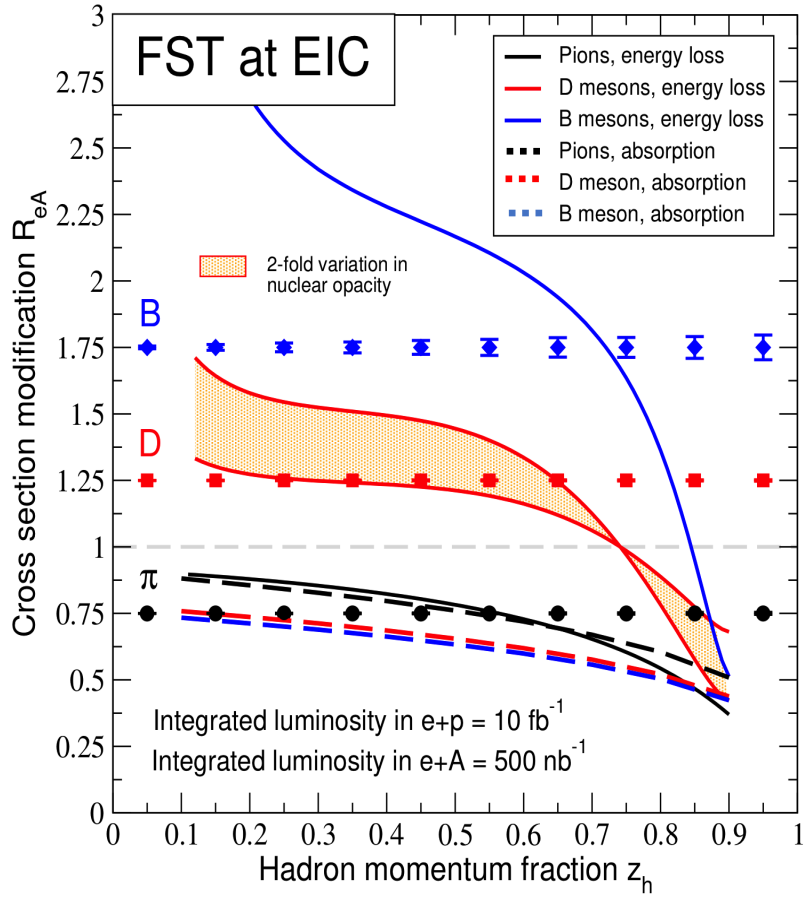


- To understand the nuclear medium effects on hadron production such as 1) modification on initial nuclear PDFs and 2) final state hadronization processes through the comparison of measured heavy flavor hadron/jet cross section between e+p and e+A collisions.

New EIC physics observables to explore hadronization are under study

- Competing models of nuclear modification in DIS reactions with nuclei (e.g HERMES data). Differentiation not possible with light hadrons.
  - Hadronization inside nuclear matter (dashed lines).
  - Energy loss of partons, hadronization outside the nuclear matter (solid lines).
- Heavy mesons have very different fragmentation functions and formation times
  - Easy to discriminate between larger suppression for D/B mesons (in-medium hadronization) and strong/intermediate z enhancement (E-loss).
  - Enhanced sensitivity to the transport properties of nuclei.
- A Forward Silicon Tracking (FST) detector is required to provide precise vertex/track measurements in the asymmetric collisions at the EIC.

EPJ Web of Conferences 235, 04002 (2020)



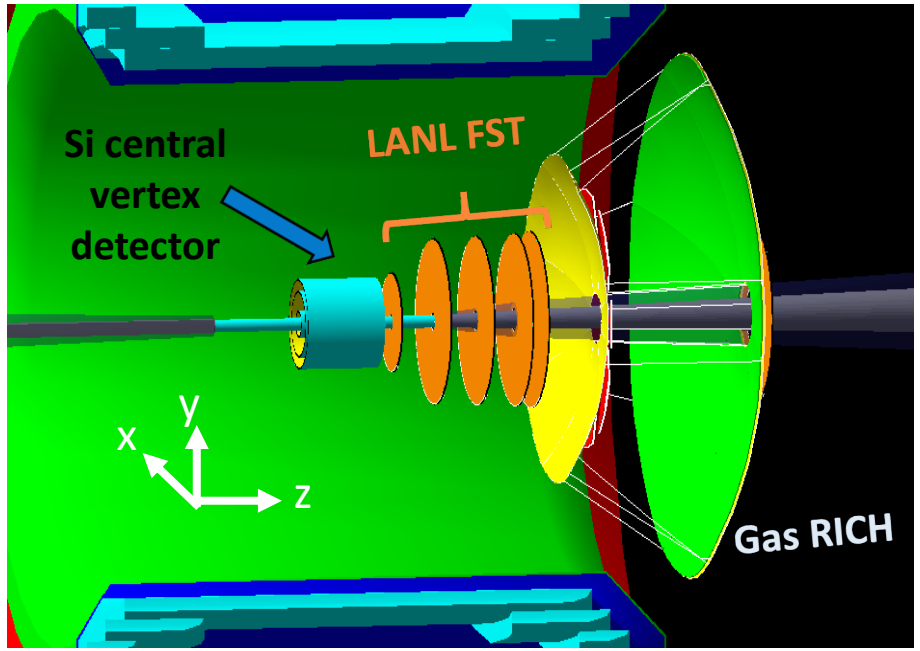
Projected stat. uncertainties at event generation level and include evaluated sampling efficiencies.

Conceptual design of the proposed Forward Silicon Tracking detector

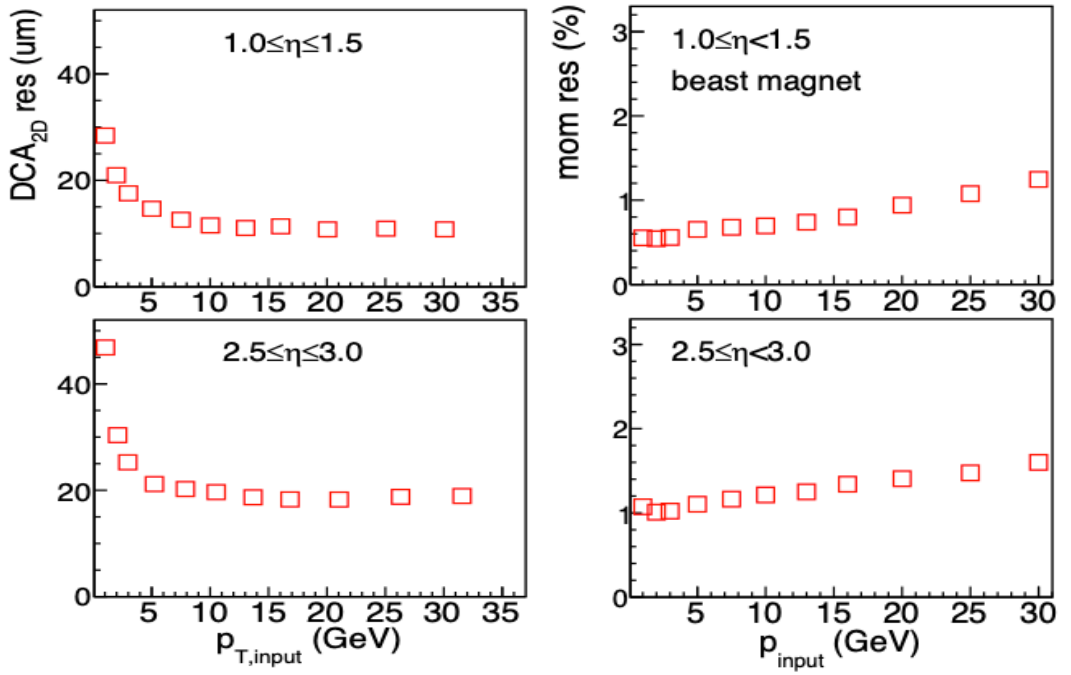
- In GEANT4 simulation with the Fun4All framework:
  - Assumed mid-rapidity silicon vertex detector with 5 barrel layers based on the Monolithic Active Pixel Sensor (MAPS) type technology.
  - Forward-rapidity silicon tracking detector (FST) with $1.0 < \eta < 3.5$: 3 planes of MAPS silicon detector and 2 forward planes of HV-MAPS silicon detector.

LANL FST integrated inside the EIC

arXiv:2009.02888



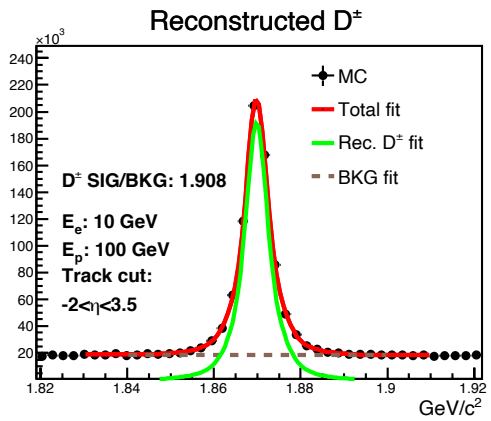
LANL FST tracking performance meets the open heavy flavor reconstruction requirements

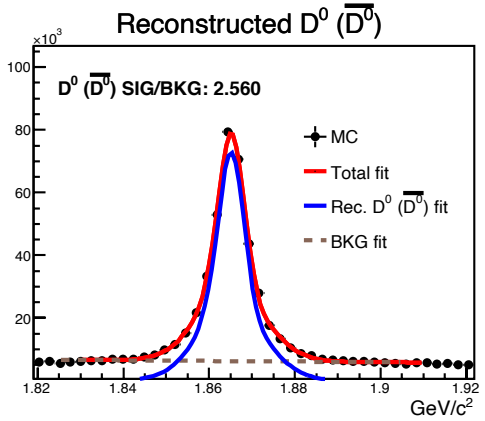


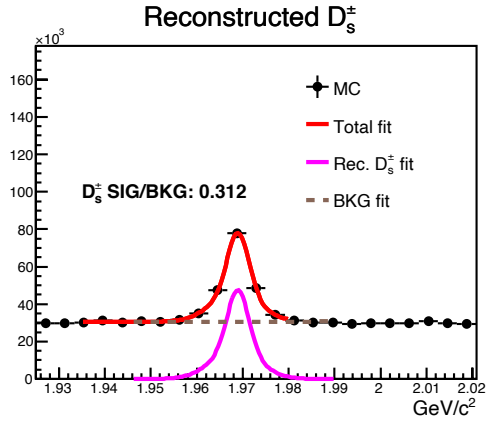
See more details in C.P Wong's talk in session MQ!

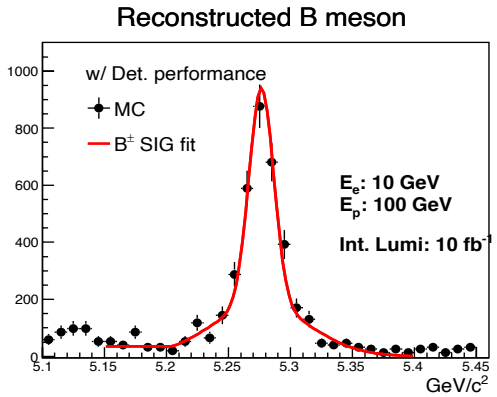
Reconstructed heavy flavor hadron with the proposed FST in simulation

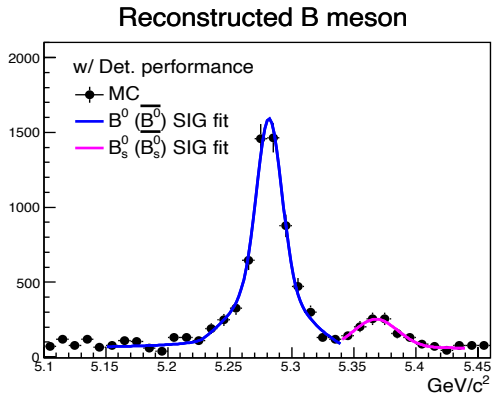
- The full analysis framework which includes the event generation (PYTHIA), detector response in GEANT4 simulation, beam remnant & QCD background, and hadron reconstruction algorithm have been setup.
- Mass distributions of reconstructed D-meson and B-meson family in 10 GeV electron and 100 GeV proton collisions with integrated luminosity: 10 fb^{-1}.











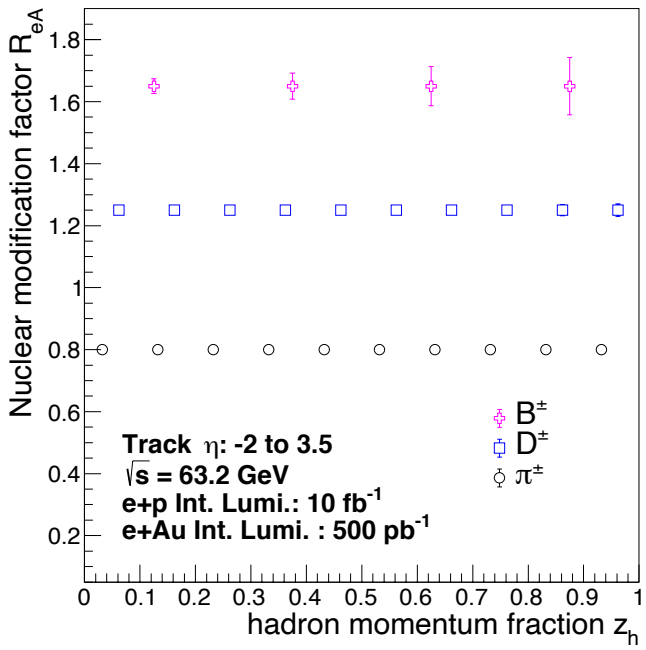
arXiv:2009.02888

- Central, backward and forward tracking performance.
- Primary vertex resolution: 20-35 (μm) depends on the track multiplicity.
- 95% K/π/p separation over all the acceptance.
- Charged track clusters with a decay length (DCA) cut.

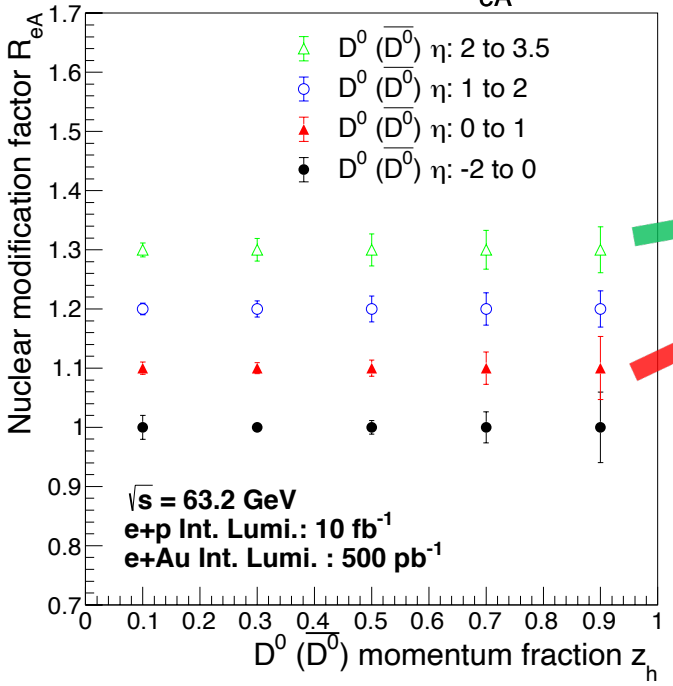
Flavor dependent nuclear modification factor projections for reconstructed hadrons

Inclusive **arXiv:2009.02888** ***η* dependent**

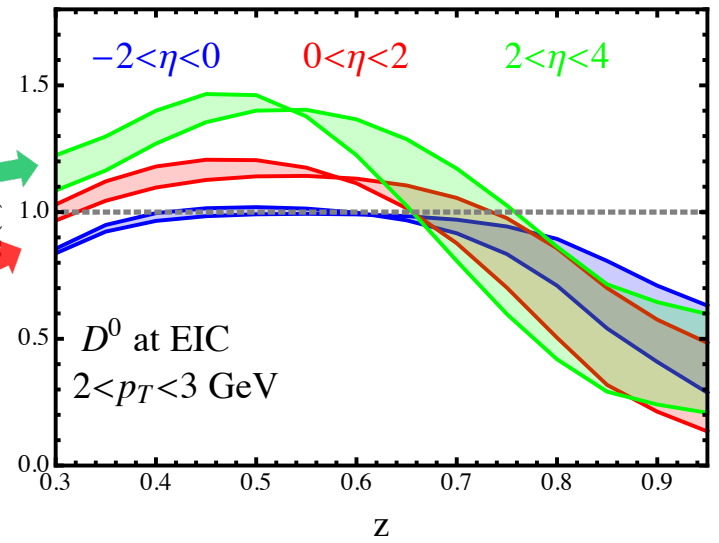
Projected hadron R_{eA} vs z_h



Projected D^0 ($\overline{D^0}$) R_{eA} vs z_h



NLO calculations

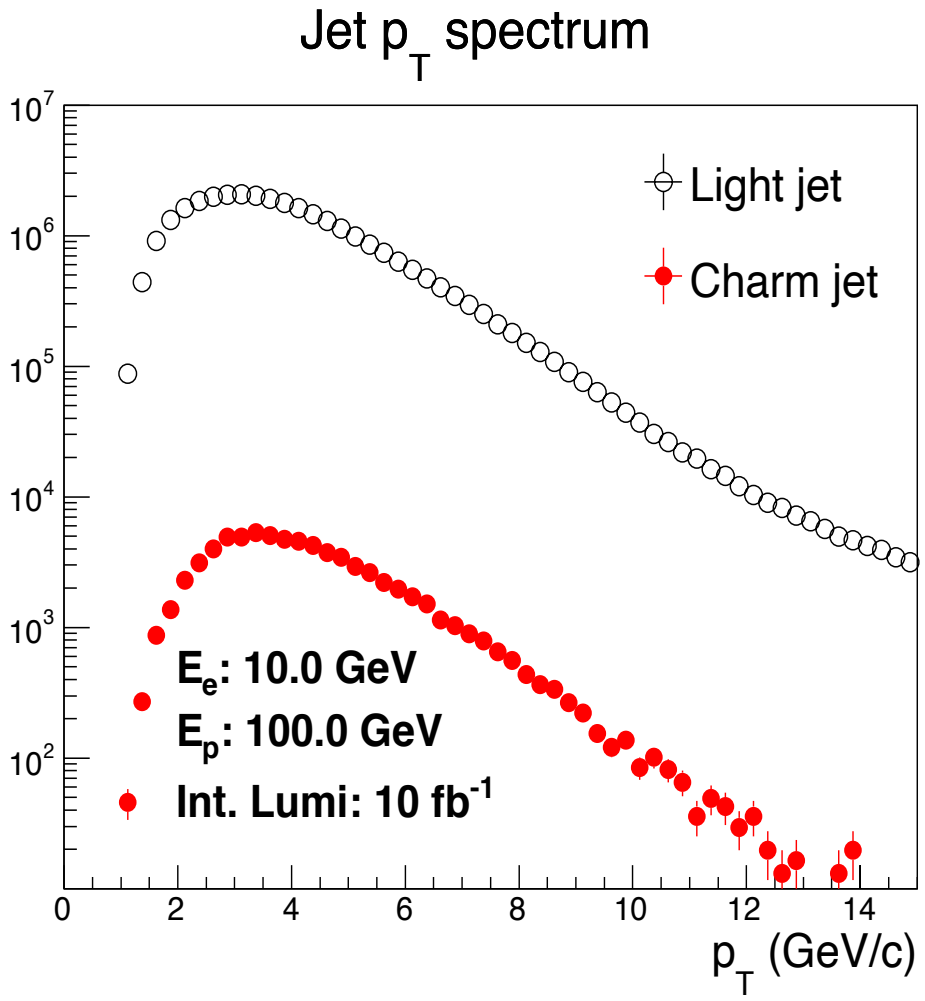


HF tomography in EIC, arXiv: 2007.10994

- The statistical precision of reconstructed hadrons can help separate different models of the nuclear modifications on the hadronization process.
- Heavy flavor measurements at the EIC will enhance the sensitivity of the nuclear transport properties.

Inclusive jet studies with different flavors

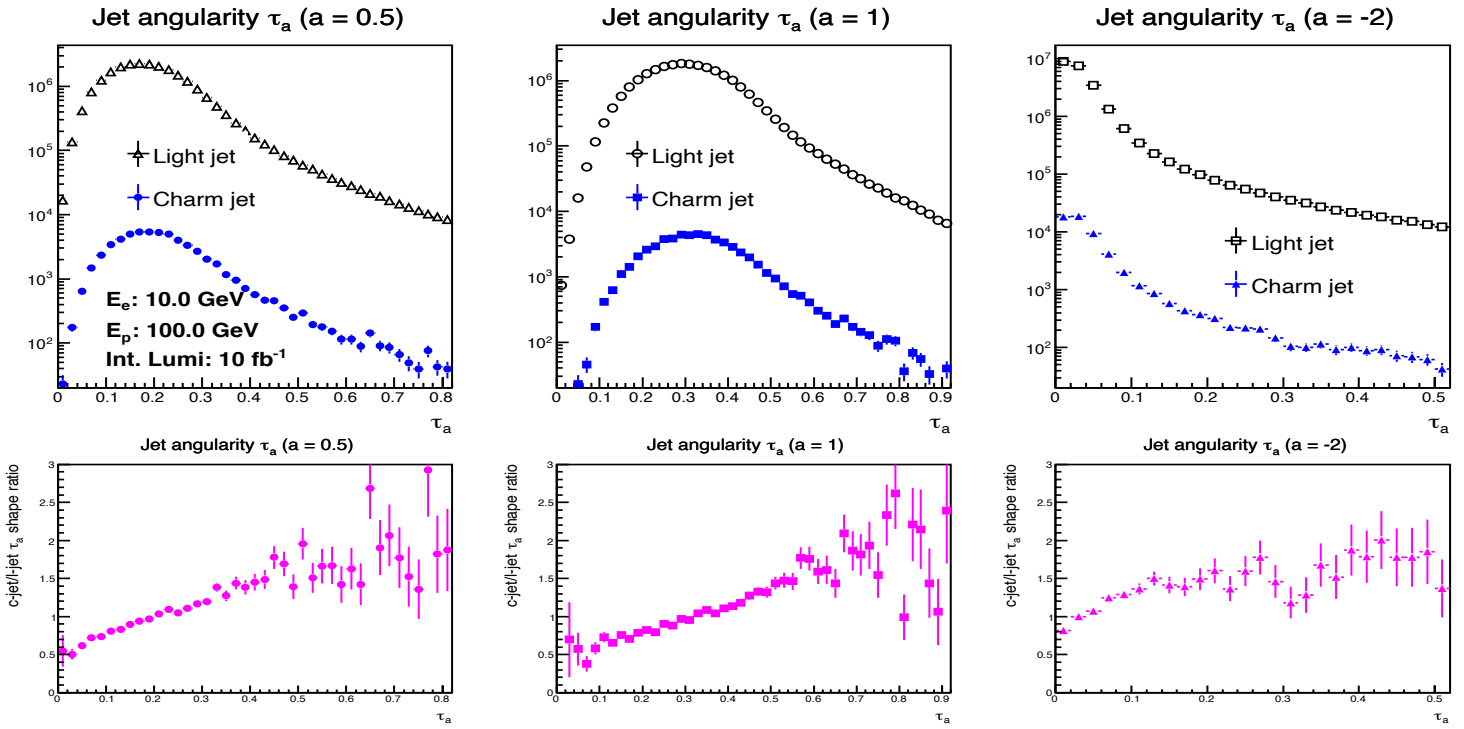
- Reconstructed jets with the detector response in simulation for 10 GeV electron and 100 GeV proton collisions with 10 fb^{-1} integrated luminosity.
- Jet algorithm: Anti-k_T with cone radius 0.8.
- Tag charm-jets with at least one charm hadron inside the jet cone.
- If no heavy flavor hadrons are found inside the jet cone, tag this jet as a light flavor jet.
- Jet yields are not corrected by the reconstruction efficiency yet.

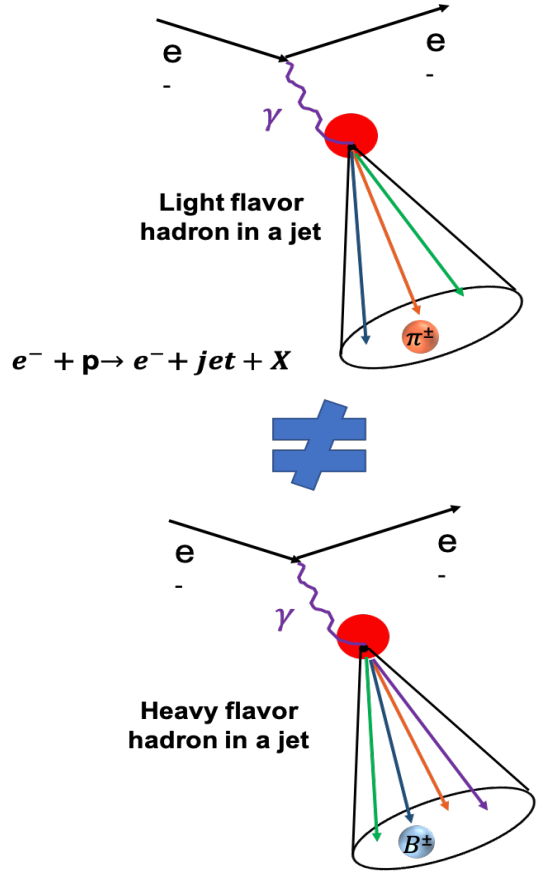


Jet substructure for different flavor jets

- A new probe to explore the hadronization origin and process: jet angularity.

Definition: $$\tau_a \equiv \tau_a^{pp} \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta \mathcal{R}_{iJ}\right)^{2-a}$$ JHEP 1804 (2018) 110

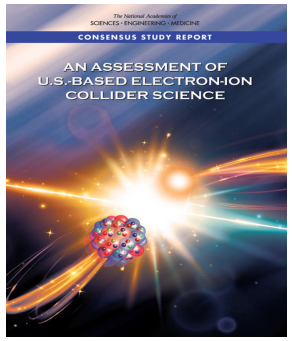


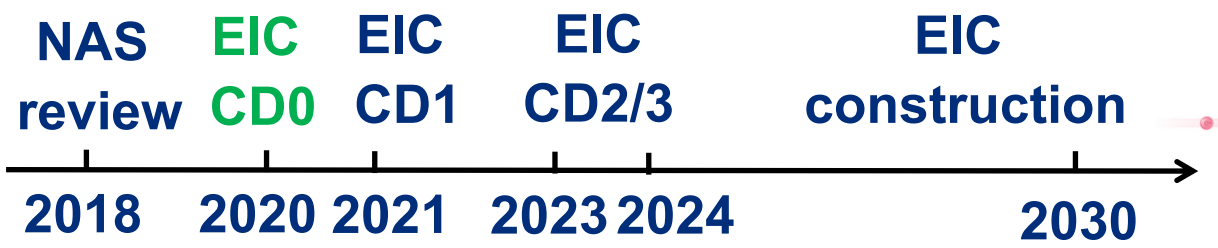


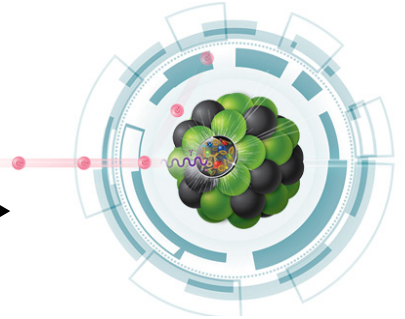
- Jet origin from a quark/gluon can be distinguished from this study.
- Shed light into how quark/gluon recombined into final hadrons with different masses.
- Impacts by nuclear medium effects will be studied in e+A collisions.

Summary and Outlook

- The new heavy flavor and jet program for the EIC will explore the flavor dependent energy loss and parton fragmentation processes in the poorly constrained kinematic region.
- We look forward to work with more collaborators and contribute to the EIC realization.







Expert level discussions of heavy flavor physics and implications for EIC

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Opportunities with Heavy Flavor at the EIC - a CFNS Ad hoc Workshop

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Virtually Online
US/Eastern timezone

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Organizers: Christian Weiss, Fredrick Olness, Ivan Vitev, Jin Huang, Xuan Li

Backup

D-meson kinematics

- In 10 GeV electron and 100 GeV proton collisions with integrated luminosity: 10 fb^{-1}